CHAPTER V

Bacteriologic Studies

DURING the course of the study, various bacteriologic characteristics related to operative infections were investigated. Comprehensive evaluation of bacteriologic factors pertaining to the patient and his operation was not possible because of the time and labor required to evaluate the many patients included in the study. Therefore, bacteriologic investigation was concentrated on those factors most directly involved in the occurrence of wound infections and the vectors most logically influenced by ultraviolet irradiation. Three vectors were chosen for study: 1) the respiratory tracts of the personnel involved in the operative treatment of the patients; 2) the environmental air of the operating room; and 3) the patients themselves, by identification of bacteria present in their wounds after operation.

These studies were conducted in the same fashion (Appendix C) by all five institutions. In addition, some individual investigators emphasized and investigated in more detail certain bacteriologic aspects of the surgical procedures. One institution studied in detail the presence of contaminating bacteria in the operative wound just before the completion of the operation; another used more refined methods of analyzing the airborne bacteria in the operating room.

Every individual entering the operating room during the course of the study was required to submit to a culture of the anterior nares every two weeks. The principals involved were the operating surgeons and all their assistants, the instrument nurse, the circulating nurse, the anesthetist and his assistants, the orderlies and attendants who entered the operating room, and all observers. Although obtaining cultures every two weeks is not equivalent to a continuous evaluation of the bacterial flora of the personnel, it does permit, by means of the accumulation of data, a reasonably accurate estimate of the average exposure of the operating room to bacteria from such a vector. The anterior nares were selected as a source of the bacteriologic evaluation because previous studies had indicated that they are often representative of the whole body in its propensity to harbor the virulent staphylococci. The subsequent management of the personnel cultures was directed primarily toward the detection of coagulase-positive staphylococci and the bacteriophage types found.

The type and number of bacteria present in the air of the operating room were determined by methods thought to match closely the probable means of contamination of the operative incision by this vector. Because this would involve the sedimentation from the air into the open wound or onto sterile instruments, gloves, or linen used in the operation, the selected means of evaluating this vector was the use of blood-agar sedimentation plates. To estimate the rate of bacterial fallout, the plates were exposed to the air for one-hour intervals chosen throughout the operating day. To evaluate and eliminate the continued germicidal effect of ultraviolet irradiation on bacteria which had already sedimented on these plates, the plates were exposed to the air in pairs, of which one member was shielded from ultraviolet rays by means of the specially designed Hart grid. This grid permitted free vertical flow of sedimenting air but shadowed the underlying culture plate from the ultraviolet

rays. The sedimentation plates were placed as close to the sterile operating field as practicable and in comparable positions in each study operating room. The blood-agar plates were later incubated and all organisms present were identified (Appendix C).

In evaluating the patient as a vector in the occurrence of an infection, wounds were cultured just before being closed (in one hospital), by the methods outlined in Appendix C. All organisms isolated were identified, and the phage sensitivity patterns and selected antibiograms of coagulase-positive staphylococci were determined.

In addition to culturing the above "potential vectors," all drainage from the wound or from any drain sites during the 28 days following operation was studied bacteriologically, including the identification of all types of bacteria present and the further identification of all isolated coagulase-positive staphylococci by bacteriophage typing and selected antibiograms. Obtainable material draining from the wound or associated drain sites was followed up postoperatively, at three-day intervals until clinical evidence of infection was apparent in the wound, or until drainage ceased.

Bacteriologic Survey of Personnel

As noted above, the protocol of the study called for a bacteriologic survey at two-week intervals of all personnel entering the operating room. In practice, this included only those personnel present on the day of the survey, and many individuals thus were not examined every two weeks. Furthermore, the irregular and transient assignment of medical students, nurses, and others to particular operating rooms resulted in many cases of a person's contributing only one or two cultures. Although the two-week interval precluded a continuous evaluation of the bacterial flora of the personnel, the flora obtained from specific individuals was surprisingly consistent, and the survey of all those present on any one day afforded a reasonably accurate estimate of the average exposure of the operating room to bacteria from personnel.

Specimens were obtained for culture by swabbing each external naris with a single dry swab, and then spreading the swab over the surface of a single blood-agar plate, which was incubated for 24 to 48 hours at 37° C. Moss, Squire, and Topley (1948), Miles (1944), and others have indicated the primary importance of the nasal origin over other, less consistent carriage sites of the staphylococci. Definitive bacteriologic studies were done on staphylococci, but the presence of beta-hemolytic streptococci was also noted. A single colony of each distinct morphological type of staphylococcus was picked and tested for coagulase activity. All coagulase-positive staphylococci were characterized by phage

Table 55. Coagulase-Positive Staphylococci Recovered From Operating-Room Personnel

Source	Number of cultures	Coagulase-positive Staph. recovered	
		Number	Percent
Hospital 1	1,440	248	17.2
Hospital 2	2,888	388	13.4
Hospital 3	1,654	512	31.0
Hospital 4	1,514	287	19.0
Hospital 5	1,767	485	27.4
Totals	9,263	1,920	20.7

Table 56. Summary of Culture-Negative Hospital 3 Personnel, January, 1960, Through February, 1962

Number of persons with only 1 culture	75
Number of persons with 2 to 4 cultures	67
Number of persons with 5 to 9 cultures	29
Number of persons with 10 to 19 cultures	19
Number of persons with 20 to 29 cultures	6
Number of persons with 31 cultures	1
Total number of persons	197
Total number of cultures	860*

*Twenty-four of the 1,654 cultures shown in Table 55 were not used in this analysis.

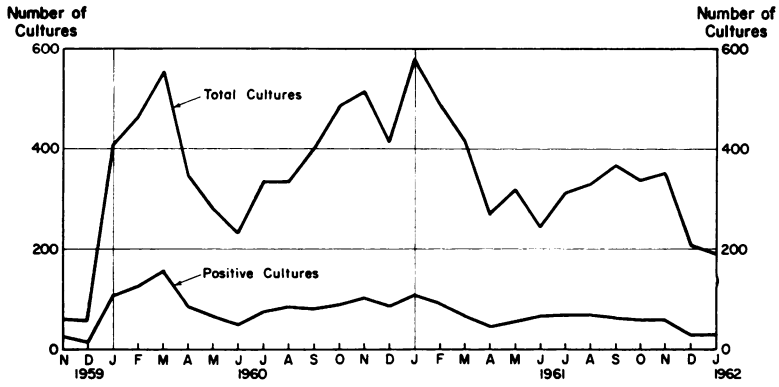

FIG. 33. Number of personnel cultures taken and number that yielded coagulase-positive staphylococci, combined hospitals.

typing and antibiograms. One institution comprehensively identified all bacteria obtained in the personnel cultures.

The incidence of coagulase-positive staphylococci recovered from the anterior nares of operating-room personnel is shown in Table 55.

These carrier rates are somewhat lower than those recorded by several authors (Artz and Grogan, 1961; Henderson and Eisses, 1960; Nahmias and Eickhoff, 1961; Lepper, Jackson, and Dowling, 1955; Howe, 1956). The number of cultures taken in the various months of the entire study ranged from 53 to 580. Despite this variation, the proportion of the operating-room personnel carrying coagulase-positive staphylococci remained remarkably constant (Fig. 33); the percentage of nasal carriers varied between 14 and 42 per cent for the combined hospitals.

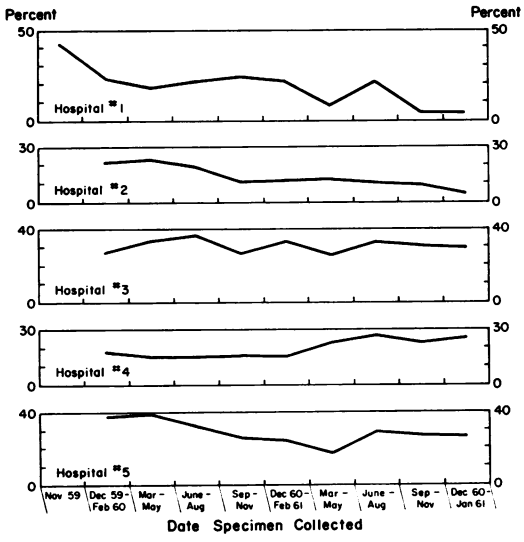

FIG. 34. Per cent of personnel cultures that yielded coagulase-positive staphylococci, by date specimen collected and hospital.

The percentage of such cultures showing coagulase-positive staphylococci in each hospital is shown in Figure 34. There is no particular correlation between the quarter of the year and the incidence of coagulase-positive cultures. (More detailed analyses on a monthly basis are found in Table D-1.*)

The patterns of the staphylococcus carrier state can be seen from the analysis of the personnel cultures from Hospital 3. The nares of 329 persons were cultured at least once during the period of January, 1960, to February, 1962. Of these, 197 (almost 60%) had no cultures positive for staphylococci at any time. The cultures of that group are summarized in Table 56.

The remaining 132 persons each had at least one positive culture recorded; their cultures are summarized in Table 57.

In the Hospital 3 experience, the nares of many people examined repeatedly showed little tendency to be colonized by coagulase-positive staphylococci, except for transient periods. Those people prob-

* Tables whose designations are prefixed by "D" are grouped in Appendix D.

ably represent the high loss rate of the occasional carrier described by Clarke (1957a). Many of the individuals represented in Table 57 showed an apparent difficulty in ridding themselves of a specific strain of staphylococcus. Among those in whom a negative culture followed a positive culture, many soon reverted to another period of consistent colonization. The new colonizing strain was only infrequently the same as the previous one.

Varying opinions have been expressed in the literature as to the likelihood of freeing an individual from his carrier status (Clarke, 1957a; Robinson, Goley, Bruton, and Baker, 1960; Martin, Nichols, and Henderson, 1960; Weinstein, 1959a; Jarvis and Wigley, 1961). It was attempted only sporadically in this series, and then on the basis of requests by the individuals. In most instances, the use of bacitracin-neomycin ointment in the nose three or four times a day resulted in a negative culture for four to six weeks, but thereafter the colonization tended to recur as a different phage type. In only one instance did reversion to a negative state appear permanent. In that individual, nine consecutive nasal cultures were positive for *Staphylococcus aureus*, phage type 80,81, between January 20 and May 25, 1960. Treatment with systemic antibiotics and intranasal antibiotic ointment resulted in one negative culture on June 8, 1960, only to be positive for phage type 80,81 12 times between June 28, 1960, and January 25, 1961. On February 8, 1961, a slightly modified phage pattern (52,52A, 80,81) was encountered. Retreatment, coincidentally undertaken at that time, resulted in nine consecutive negative cultures throughout the remainder of the study.

At one institution, Hospital 4, comprehensive identification of all bacteria obtained from personnel cultures showed

Table 57. Summary of Culture-Positive Hospital 3 Personnel, January, 1960, Through February, 1962

Number of persons with only 1 culture	34
Number of persons with 2 to 4 cultures	44
26 persons had no negative cultures	
18 persons had 2 or more positive cultures of the same phage type*	
Number of persons with 5 to 9 cultures	31
12 persons had no negative cultures	
13 persons had 2 or more positive cultures** of the same phage type*	
6 persons had all cultures negative except one or two of scattered** types*	
Number of persons with 10 or more cultures	23
4 persons had no negative cultures	
2 persons had only 1 negative culture	
6 persons had 2 to 4 positive cultures** of the same phage type*	
10 persons had 5 or more positive cultures** of the same phage type*	
Total number of persons	132
Number of positive cultures	540
Number of negative cultures	230
Total number of cultures	770†

*Nontypable strains are not considered to be necessarily identical in this table, even when similar antibiograms were observed.

**Not necessarily consecutively positive.

†Twenty-four of the 1,654 cultures shown in Table 55 were not used in this analysis.

Table 58. Organisms Isolated From 1,693 Hospital 4 Personnel Cultures, November 1, 1959, Through January 31, 1962

Organism	Number	Frequency, percent
Aerobacter		
aerogenes	40	2.4
cloacae	3	0.2
species	1	0.1
Bacillus species	39	2.3
Diphtheroid		
aerobic	201	11.9
anaerobic	4	0.2
Diplococcus	1	0.1
Escherichia		
coli	13	0.8
intermedium	10	0.6
Flavobacterium species	1	0.1
Gaffkya species	68	4.0
Micrococcus species	247	14.6
Neisseria species	4	0.2
Paracolobactrum		
aerogenoides	3	0.2
coliform	1	0.1
intermedium	11	0.6
species	1	0.1
Proteus		
mirabilis	8	0.5
vulgaris	1	0.1
species	6	0.4
Pseudomonas species	1	0.1
Sarcina species	36	2.1
Serratia species	1	0.1
Shigella species	1	0.1
Staphylococcus		
coagulase-negative	1,256	74.2
coagulase-positive	314	18.5
Streptococcus		
alpha-hemolytic	2	0.1
beta-hemolytic	37	2.2
nonhemolytic	76	4.5
Total number of organisms isolated	2,387	

Table 59. Frequencies of Recovery of Various Organisms on Sedimentation Plates

Type of organism	Number of plates on which recovered			
	Shielded plates		Unshielded plates	
	UV	Control	UV	Control
Coagulase-positive staphylococci	23	87	13	89
Coagulase-negative staphylococci	1,116	1,315	867	1,266
Alpha-hemolytic streptococci	13	18	9	19
Beta-hemolytic streptococci	9	20	5	18
Nonhemolytic streptococci	22	30	18	33
Escherichia sp.	2	9	2	8
Aerobacter-Klebsiella	4	6	4	7
Paracolobactrum sp.	5	3	5	3
Proteus sp.	5	6	1	3
Pseudomonas sp.	2	4	6	10
Other identified organisms	1,013	1,186	913	1,119
Unidentified organisms	67	85	53	82
No organisms	589	282	859	296
Total number of plates	2,231	2,169	2,240	2,166
Mean plate count, colonies/plate	6.85	15.69	4.88	16.00

that all cultures were positive for some organisms in the period of November, 1959, through January, 1962. From the 1,693 cultures a total of 2,387 organisms were isolated. Table 58 lists the types of organisms found and their frequencies. Coagulase-negative staphylococci were encountered most frequently, with coagulase-positive staphylococci, micrococci, and the aerobic diphtheroids, distant second, third, and fourth, respectively.

Bacteriologic Survey of Operating-Room Air

Two blood-agar plates were simultaneously exposed to the air in the operating room, as mentioned earlier. One plate was shielded from ultraviolet irradiation by the Hart grid, which was constructed of vertical stainless-steel plates perpendicular to each other and forming one-inch-square cells. The grid was fitted with legs to permit placement of the Petri plate underneath. After exposure for one hour the shielded and unshielded plates were each incubated at 37° C. for 24 and 48 hours. Colony counts were made and all organisms were identified. Coagulase-positive staphylococci were phage-typed and tested for sensitivity to antibiotics.

Evaluation of airborne bacteria in the operating room by means of sedimentation plates revealed that ultraviolet irradiation decreases the total number of viable bacteria present in this environment. Of the 8,806-blood agar plates exposed, 4,406 were unshielded and 4,400 were shielded. Approximately half of each group were exposed in the absence of ultraviolet radiation; in the control (unirradiated) rooms, the mean counts were found to be 15.69 colonies/plate on shielded plates and 16.00 colonies/plate on unshielded plates (Table 59). In the irradiated rooms, the mean counts were 6.85 colonies/plate on shielded plates and 4.88 colonies/plate on unshielded plates.

It is of interest to note that about one-fourth of the shielded plates in irradiated rooms were not colonized at all by bacteria, nor were over a third of the unshielded plates in those rooms. However, only one-eighth of the plates exposed in the control rooms remained sterile. Analysis of the types of organisms settling from the air indicates that the intensity of ultraviolet radiation used in this study still permits a wide variety of bacteria to survive. Attention is also called to the fact that all the plates were incubated only aerobically, with no attempt being made to detect anaerobic bacteria.

The vast majority of organisms recovered from the air were coagulase-negative staphylococci. Coagulase-positive staphylococci and streptococci were recovered from the air, but on considerably fewer plates. The remainder of the organisms listed in Table 59 were only rarely recovered. A wide variety of bacteria were, however,

Table 60. Sedimentation-Plate Results, by Ultraviolet Intensity

Intensity	Type of plate			
	Shielded		Unshielded	
	UV	Control	UV	Control
Initial				
Number of plates	1,162	1,127	1,167	1,123
Mean plate count, colonies/plate	8.03	16.34	5.51	16.64
Increased				
Number of plates	1,057	1,028	1,055	1,025
Mean plate count, colonies/plate	5.54	14.97	4.18	15.31

recovered, as indicated by the numbers of *other identified organisms.* That category includes the genera Achromobacter, Alcaligenes, Bacillus, Corynebacterium, Flavobacterium, Gaffkya, Micrococcus, Neisseria, Sarcina, and Serratia, and fungi. *Micrococcus sp., Bacillus sp.,* and *Corynebacterium sp.* were the most frequently isolated of this group.

The coagulase-positive staphylococci appeared to be the most sensitive to the lethal effects of ultraviolet irradiation, on the basis of the observed reductions in the frequencies with which specific organisms were recovered.

It was found necessary to change the ultraviolet intensity during the course of the study (Chapter III). Table 60 shows the mean colony counts of the sedimentation plates exposed under the initial and the increased intensities. Under initial conditions (average of 15.5 μw/cm.^{2} with a range of 12 to 22 μw/cm.^{2}), the fallout of viable airborne organisms was reduced by 50.9 per cent, the mean shielded plate count declining from 16.34 colonies/plate in control rooms to 8.03 colonies/plate in irradiated rooms. A greater reduction, 63.0 per cent, was observed under increased intensity (20 to 24 μw/cm.^{2}), the mean counts being 14.97 and 5.54 colonies/plate for control and irradiated rooms, respectively.

The similarity of mean plate counts on shielded and unshielded plates (Table 60) obtained in control rooms, 16.34 and 16.64 colonies/plate, respectively, for the initial intensity, and 14.97 and 15.31 colonies/plate for the increased intensity, indicates that the ultraviolet shields did not significantly interfere with bacterial fallout.

Comparison of the numbers of viable settling bacteria in each of the operating rooms of the participating institutions reveals a wide range of bacterial fallout. Table 61 indicates, for example, that the mean number of bacteria settling per hour

Table 61. Mean Shielded Plate Counts, by Operating Room

Operating room	Mean plate count, colonies/plate	
	UV	Control
Hospital 1		
room 1	5.90	13.38
room 2	5.47	13.20
Hospital 2		
room 2	5.04	13.58
room 3	4.55	9.63
room 4	4.08	11.36
Hospital 3		
room 1	15.78	31.19
room 2	17.94	42.05
room 3	11.31	19.37
Hospital 4		
room 1	1.74	4.21
room 2	6.09	14.79
room 3	5.77	14.62
Hospital 5*		
room 1	5.15	19.54
room 2	8.39	12.12
room 3	6.83	12.19
room 4	11.15	18.11
room 5	6.08	10.62

*High-intensity phase only.

under irradiation was 1.74 in operating room 1 of Hospital 4, but 17.94 in operating room 2 of Hospital 3.

Figure 35 shows the mean colony counts of bacteria settling in the operating rooms by combined and individual hospital experience. The time of exposure was nor-

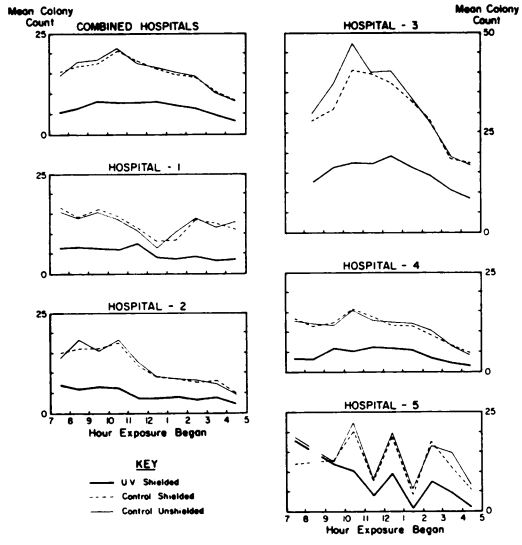

FIG. 35. Mean sedimentation-plate colony counts, by time of day and hospital.

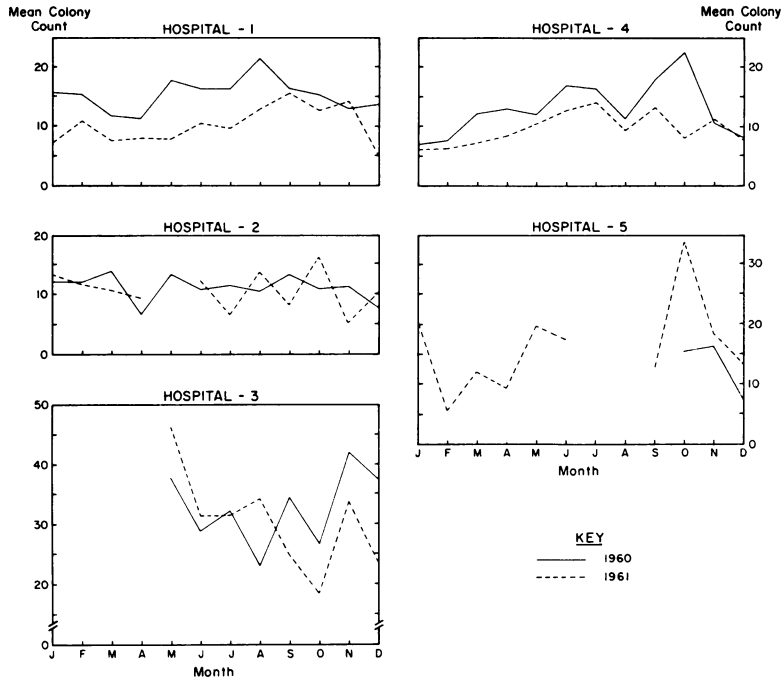

FIG. 36. Mean sedimentation-plate colony counts, control plates (shielded and unshielded) only, by month.

mally 7 a.m. to 5 p.m. in each hospital, with the exception of Hospital 5, where no plates were exposed between 8 and 9 a.m. The average plate counts for shielded and unshielded *control* plates are very similar for each hospital, and generally about twice those for shielded *irradiated* plates. The pattern of results in each hospital shows marked differences, however, according to time of day. These differences may be due to peculiarities of operating-room scheduling in specific hospitals. The most unusual pattern developed in Hospital 5, where the data suggest that operating-room activity between 10 a.m. and 2 p.m. is greater for the even-numbered hours.

The graph representing the combined hospital data, however, indicates that the sedimentation rate is relatively low at the beginning of each day, increases during the morning hours to a peak at about 10:30, and gradually decreases through the day. This pattern is apparent in the data of each hospital, and the midmorning peak can be correlated with the peak of activity in the operating rooms during the morning hours, which quickly raises the degree of bacterial contamination of the environment.

Figure 36 depicts the mean colony counts for control plates in each hospital on a monthly basis for 1960 and 1961. The patterns are not marked and vary by hospital. For Hospitals 3 and 5, plates were not exposed continuously in all the months in question.

Some of the organisms recovered from shielded and unshielded control plates are plotted in Figure 37 by quarter year. The proportion of plates demonstrating coagulase-positive staphylococci fluctuated. The presence of these organisms varied from 1.0 per cent during December, 1961, and January, 1962, to a high of 5.9 per cent during September, October, and November, 1960. The average for the entire study was 4.1 per cent. Coagulase-negative staphylococci were recovered most frequently, being found on 59.5 per cent of

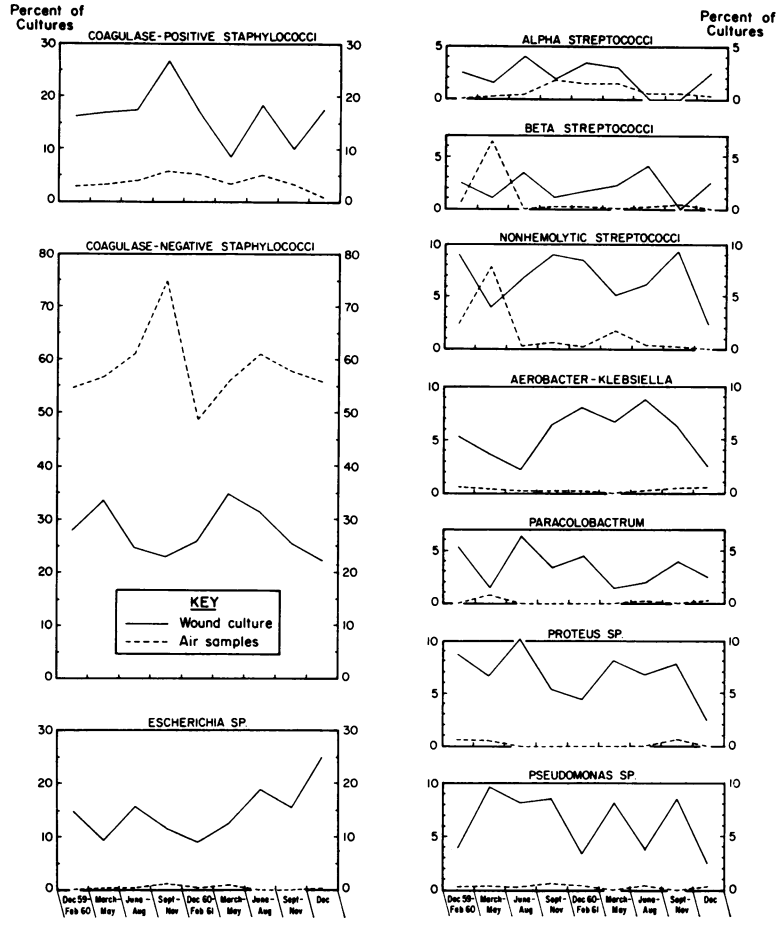

FIG. 37. Comparison of frequency of recovery of specific organisms from control sedimentation-plate cultures and from wound-drainage cultures.

the control plates. Their occurrence in the air is quite stable, the proportion of plates yielding these organisms varying from 48.9 to 74.8 per cent for the quarterly intervals plotted. The frequency of recovery of these organisms is shown by hospital in Table 62. Alpha-hemolytic streptococci were found only sporadically in the operating-room air. However, between September, 1960, and May, 1961, they were recovered quite regularly, owing to an extended appearance in Hospital 2. Otherwise, the occurrences were widely scattered by time and by hospital. All the beta-hemolytic streptococci were recovered in Hospital 4. Four of the five hospitals recovered nonhemolytic streptococci at one time or another, the most continuous period of recovery being February to May, 1960, in Hospital 4; otherwise, the organisms appeared only sporadically. It is interesting to note that the high incidences of beta-hemolytic and nonhemolytic streptococci occurred simultaneously in Hospital 4.

The graphs of Figure 37 also show the incidence of recovery of organisms from some 1,900 cultures of about 1,400 postoperative wounds. These were plotted to determine whether a high rate of recovery of a given organism from sedimentation plates during a given period was associated with a high rate of recovery from postoperative wound cultures of operations performed during that period. The graphs reveal no such relationship.

Table 62. Frequency of Recovery of Coagulase-Negative Staphylococci on Control Sedimentation Plates, by Hospital

Hospital	Frequency of recovery, percent
1	76.1
2	81.6
3	87.3
4	13.6
5	83.1

Bacteriologic Survey of Wounds Cultured at Time of Operation (Hospital 4)

One hospital conducted a special study in which cultures were obtained by washing incisions with 10 ml. of sterile physiological saline just before closure. All organisms recovered from the aspirated saline were identified at the species level and all isolated coagulase-positive staphylococci were further identified by bacteriophage typing and antibiograms.

The reasons for obtaining such cultures were 1) to learn whether the flora recovered from operative wounds just before closure resembled the flora generally recovered from sedimentation plates; 2) to learn whether the frequency of recovery of various organisms varied significantly with wound classification; 3) to determine the frequency with which certain species of bacteria found in the wound at operation persisted and were recoverable from postoperative drainage; 4) to determine the influence of certain species of bacteria in the wound at operation on the likelihood of postoperative infection; and 5) to learn whether ultraviolet irradiation affects the prevalence of organisms recoverable from the wound at operation.

Of the 1,186 * wounds cultured, 590 (49.8%) were irradiated, and the remaining 596 (50.2%) were not. Table 63 indicates the numbers of wounds of each classification from which no organisms were recovered, that is, the numbers of sterile cultures, and Table 64 summarizes the same data divided according to ultraviolet irradiation status.

When the protocol definitions of wound classifications are considered, the frequencies of sterile cultures obtained from nonclean wounds may seem paradoxical, but reports of sterile cultures of traumatic, as well as operative, wounds are not infrequent. Schönbauer and Demel (1923) reported that 20 of 21 thyroidectomy wounds were sterile when cultured just before the musculature was sutured, and that similar cultures of wounds from major operations involving the stomach and gallbladder were sterile if the operation did not last longer than 1¼ hours. After longer operations, *Staphylococcus albus* was usually recovered. Byrne and Okeke (1957) reported 80.7 per cent of operative wounds cultured just before closure to be sterile. Reports of accidental wounds sterile by culture include those of Melchior and Lubinski (1923), Serck-Hanssen (1930), Dimtza and Gutscher (1933), Newell (1934), Spooner (1941), Hare and Willits (1942), Munro (1942), White (1944), and deWaal (1945).

The frequency of sterile wound cultures is not surprising when one considers the various factors that may influence the results. The sampling method employed in culturing the wound just before closure may not have been adequate to detect organisms present in the wound in small numbers. Even in the presence of a frank abscess, one may frequently obtain a "sterile" culture unless the peripheral wall or

Table 63. Frequency of Sterile Operative Cultures, by Wound Classification

Wound classification	Number of cultures	Number of sterile cultures	Frequency of sterile cultures, percent
Clean	824	574	69.7
Clean-contaminated	298	172	57.7
Contaminated	35	16	45.7
Dirty	29	17	58.6
Totals	1,186	779	65.7

* Two cultures of unknown wound classification are omitted from this discussion.

Table 64. Frequency of Sterile Operative Cultures, by Wound Classification and Irradiation Status

Wound classification	Irradiated			Control		
	Number of cultures	Number of sterile cultures	Frequency of sterile cultures, percent	Number of cultures	Number of sterile cultures	Frequency of sterile cultures, percent
Clean	407	305	74.9	417	269	64.5
Clean-contaminated	150	95	63.3	148	77	52.0
Contaminated	16	11	68.8	19	5	26.3
Dirty	17	9	52.9	12	8	66.7
Totals	590	420	71.2	596	359	60.2

focus of the infection is sampled. The battery of culture media employed for the initial planting of specimens is also of importance. Media free of vitamin K compounds, for example, will not support the growth of vitamin-K-dependent strains of *Bacteroides melaninogenicus* (Lev, 1958; Gibbons and MacDonald, 1960); when appropriate media and methods of sampling are employed, the frequency with which this and other anaerobic organisms are recovered from surgical infections increases significantly (Dowell, Hill, and Altemeier, 1962; Cole and Bernard, 1962). Failure to culture specimens immediately may frequently result in failure to detect some "fragile" bacteria, especially certain anaerobic streptococci and nonsporulating, gram-negative, anaerobic genera. All these factors must be borne in mind when evaluating the bacterial flora of all categories of surgical wounds.

A significantly greater proportion of wound washings were sterile in operations performed in irradiated rooms. Of the 590 irradiated wounds cultured, no organisms

Table 65. Frequency of Postoperative Infection, by Wound Classification, Irradiation Status, and Culture Results

Wound classification and culture results	Irradiated			Control			
	Number of wounds	Number of infections	Frequency of infection, percent	Number of wounds	Number of infections	Frequency of infection, percent	Overall frequency of infection, percent
Clean	407			417			
Sterile by culture	305	3	1.0	269	2	0.7	0.9
Positive by culture	102	4	3.9	148	2	1.4	2.4
Clean-contaminated	150			148			
Sterile by culture	95	1	1.1	77	1	1.3	1.2
Positive by culture	55	3	5.5	71	7	9.9	7.9
Contaminated	16			19			
Sterile by culture	11	0	0.0	5	0	0.0	0.0
Positive by culture	5	1	20.0	14	2	14.3	15.8
Dirty	17			12			
Sterile by culture	9	0	0.0	8	1	12.5	5.9
Positive by culture	8	2	25.0	4	1	25.0	25.0
Totals	590			596			
Sterile by culture	420	4	1.0	359	4	1.1	1.0
Positive by culture	170	10	5.9	237	12	5.1	5.4

Table 66. Summary of Organisms Recovered From Cultures of 1,186 Wounds at Operation, All Wound Classifications

Organism	Number of times recovered	Frequency of recovery, percent	Number of times recovered from wounds that became infected
Coag.-pos. staphylococci	29	2.4	8
Coag.-neg. staphylococci	127	10.7	5
Alpha-hemolytic streptococci	8	0.7	1
Beta-hemolytic streptococci	11	0.9	1
Nonhemolytic streptococci	38	3.2	3
Anaerobic streptococci	9	0.8	0
Escherichia sp.	37	3.1	1
Aerobacter-Klebsiella	16	1.3	1
Paracolobactrum sp.	8	0.7	2
Proteus sp.	9	0.8	1
Pseudomonas sp.	2	0.2	0
Clostridium sp.	3	0.3	0
Bacteroides sp.	5	0.4	1
Other	184	15.5	6
Unidentified	1	0.1	0
None	779	65.7	8

were recovered from 420 (71.2%), whereas only 359 (60.2%) of the 596 unirradiated wounds were sterile by culture (Table 64). This relationship exists for every wound classification except *dirty*, which included only 29 wounds.

The likelihood of postoperative infection is apparently greater when organisms are recovered from the operative cultures. Table 65 lists the numbers of definite postoperative infections in each wound classification in wounds that were sterile and positive by culture at operation. Of the 407 wounds from which organisms were recovered, 22 (5.4%) became infected postoperatively, whereas only eight (1.0%) of the 779 wounds sterile by culture became infected; the difference in frequencies is significant at the 1 per cent level. This relationship appears to exist for each wound classification.

Another interesting pattern is apparent in the data of Table 65. The postoperative infection rate in wounds found sterile at operation does not appear to differ much from 1 per cent regardless of wound classification (except for dirty wounds). In those wounds from which organisms were recovered, however, the frequency of postoperative infection ranges all the way from 2.4 per cent (clean wounds) to 25.0 per cent (dirty wounds).

Summary of Organisms Recovered. Table 66 indicates the frequencies with which various organisms were isolated from the washings of the 1,186 wounds at the time of operation. Coagulase-negative staphylococci were recovered with the greatest frequency, occurring in 127 (10.7%) of all wounds cultured, which represented 31.1 per cent of the 408 positive cultures, and they were the only organisms isolated from 107 cultures (26.2% of the positive cultures), indicating that the source was either aerial fallout, contact contamination, or the patient's skin. Although the latter two sources were not evaluated, the frequency with which these organisms were recovered from the sedimentation plates suggests aerial fallout as a likely source of the organisms found in the operative wound just before closure. The importance of the patient's skin as a source of staphylococci and the importance

of adequate preoperative skin preparation have been demonstrated by a number of authors, including Ives and Hirshfeld (1938), Hart and Upchurch (1939), Lovell (1945), Adams (1957), and Hitchcock *et al.* (1958).

The organisms occurring next most frequently were the nonhemolytic streptococci, *Escherichia sp.*, coagulase-positive staphylococci, and the *Aerobacter-Klebsiella* group. Lovell (1945) reported that wounds positive for organisms when cultured at operation contained *Staphylococcus aureus* and *Escherichia coli* more frequently than other organisms, that these were of the resident flora, and that in most instances they were apparently carried into the wound by the skin knife. The remainder of the organisms listed in Table 66 were recovered with frequencies of less than 1.0 per cent. The nonhemolytic streptococci were recovered as the sole organisms in 20 instances (the sole organisms in 52.6 per cent of the cultures from which they were recovered) and *Escherichia sp.* were recovered as the sole organisms in 17 instances (45.9% of the cultures from which they were recovered). A species of the *Aerobacter-Klebsiella* group was isolated as the only organism in nine (56.2%) of the 16 cultures from which this group was recovered.

Table 67. Frequencies of Recovery of Organisms Cultured at Operation From 30 Wounds That Developed Postoperative Infection

Organism	Number of times recovered	Frequency of recovery, percent
Coag.-pos. staphylococci	8	26.7
Coag.-neg. staphylococci	5	16.7
Alpha-hemolytic streptococci	1	3.3
Beta-hemolytic streptococci	1	3.3
Nonhemolytic streptococci	3	10.0
Escherichia sp.	1	3.3
Aerobacter-Klebsiella	1	3.3
Paracolobactrum sp.	2	6.7
Proteus sp.	1	3.3
Bacteroides sp.	1	3.3
Other	6	20.0
None	8	26.7

The *other* identified organisms indicated in the table comprise *Micrococcus sp., Bacillus sp., Sarcina sp., Gaffkya sp., Corynebacterium sp., Neisseria sp., Serratia sp.*, and yeast. Of this group, the diphtheroids and micrococci occurred with the greatest frequencies.

Frequency of Organisms Cultured From Wounds Which Became Infected. Of the 1,186 wounds cultured at operation, only 30 developed postoperative infections. Table 67 indicates the frequencies with which various organisms were recovered from those 30 wounds. Eight (26.7%) of the wounds that became infected postoperatively were sterile by culture at time of operation. Though the numbers of wounds involved were small, the trend for staphylococci to occur with the greatest frequency is evident.

Table 68. Frequencies of Recovery of Organisms From Cultures of 824 Clean Wounds at Operation

	All recoveries			Recoveries involving only one organism		
Organism	Number of times recovered	Frequency of recovery, percent	Number of times recovered from wounds that became infected (total: 11)	Number of times recovered	Frequency of recovery, percent	Number of times recovered from wounds that became infected
Coag.-pos. staphylococci	12	1.5	2	8	1.0	1
Coag.-neg. staphylococci	88	10.7	2	78	9.5	1
Alpha-hemolytic streptococci	2	0.2	0	2	0.2	0
Beta-hemolytic streptococci	6	0.7	0	2	0.2	0
Nonhemolytic streptococci	24	2.9	0	15	1.8	0
Anaerobic streptococci	4	0.5	0	3	0.4	0
Escherichia sp.	10	1.2	0	2	0.2	0
Aerobacter-Klebsiella	5	0.6	0	4	0.5	0
Paracolobactrum sp.	5	0.6	0	2	0.2	0
Proteus sp.	3	0.4	0	0	0.0	-
Pseudomonas sp.	2	0.2	0	1	0.1	0
Other	119	14.4	3	107	13.0	3
Unidentified	1	0.1	0	0	0.0	-
None	574	69.7	5			

Table 69. Frequencies of Recovery of Organisms From Cultures of 298 Clean-Contaminated Wounds at Operation

Organism	All recoveries			Recoveries involving only one organism		
	Number of times recovered	Frequency of recovery, percent	Number of times recovered from wounds that became infected (total: 12)	Number of times recovered	Frequency of recovery, percent	Number of times recovered from wounds that became infected
Coag.-pos. staphylococci	9	3.0	2	6	2.0	2
Coag.-neg. staphylococci	33	11.1	2	26	8.7	1
Alpha-hemolytic streptococci	5	1.7	1	3	1.0	0
Beta-hemolytic streptococci	4	1.3	1	3	1.0	0
Nonhemolytic streptococci	13	4.4	2	5	1.7	1
Anaerobic streptococci	4	1.3	0	0	0.0	-
Escherichia sp.	16	5.4	0	11	3.7	0
Aerobacter-Klebsiella	9	3.0	1	5	1.7	1
Paracolobactrum sp.	2	0.7	1	1	0.3	1
Proteus sp.	5	1.7	1	0	0.0	-
Clostridium sp.	2	0.7	0	0	0.0	-
Bacteroides sp.	1	0.3	0	0	0.0	-
Other	54	18.1	1	39	13.1	1
None	172	57.7	2			

Frequency of Organisms Recovered From Cultures of Clean, Clean-Contaminated, Contaminated, and Dirty Wounds. *Clean Wounds.* Table 68 indicates the numbers and frequencies of recovery of organisms from 824 clean wounds cultured at operation. Of these, 574 wounds (69.7%) were sterile by culture. Of the organisms recovered, the coagulase-negative staphylococci occurred with the greatest frequency (in 88, or 10.7%, of the 824 wounds cultured). These organisms were isolated as the sole contaminants in 78 (9.5%) of the clean wounds, only one of which developed a postoperative infection. The nonhemolytic streptococci were recovered next most frequently, occurring in 24 (2.9%) of the wounds, of which 15 (62.5%) yielded these organisms in pure culture and none developed postoperative infection. The coagulase-positive staphylococci and *Escherichia sp.* followed, with incidences of 1.5 per cent (12 isolates) and 1.2 per cent (10 isolates), respectively. In eight (66.7%) of the 12 wounds in which coagulase-positive staphylococci were present, they were the sole organisms, but only one of those wounds developed a postoperative infection. Only two of the isolates of *Escherichia sp.* were recovered alone; neither wound developed a postoperative infection. Beta-hemolytic streptococci, recovered from six wounds, were recovered as the sole organisms on two occasions; neither wound developed a postoperative wound infection.

Clean-Contaminated Wounds. Cultures were obtained at operation from a total of 298 clean-contaminated wounds (Table 69), of which 172 (57.7%) were sterile by culture. Again, the most frequently recovered organisms were the coagulase-negative staphylococci, occurring in 33 (11.1%) of the wounds, 26 times (78.8%) by themselves. Only one of the 26 wounds became postoperatively infected. *Escherichia sp.* were recovered with the next highest frequency, in 16 (5.4%) of the wounds, 11 times as the sole organisms; none of these wounds developed a postoperative infection. The nonhemolytic streptococci occurred in 13 (4.4%) of the wounds, five times as the sole organisms, followed by the coagulase-positive staphylococci and the *Aerobacter-Klebsiella* group, each of which was recovered from nine wounds (3.0%); these three were recovered as the sole organisms in five, six, and five instances, respectively. Two of the wounds from which coagulase-positive staphylococci were isolated as the sole organisms developed a postoperative infection, but neither seemed caused by the strain of

Table 70. Frequencies of Recovery of Organisms From Cultures of 35 Contaminated Wounds at Operation

Organism	All recoveries			Recoveries involving only one organism		
	Number of times recovered	Frequency of recovery, percent	Number of times recovered from wounds that became infected (total:3)	Number of times recovered	Frequency of recovery, percent	Number of times recovered from wounds that became infected
Coag.-pos. staphylococci	4	11.4	2	3	8.6	1
Coag.-neg. staphylococci	3	8.6	0	2	5.7	0
Alpha-hemolytic streptococci	1	2.9	0	0	0.0	-
Beta-hemolytic streptococci	1	2.9	0	1	2.9	0
Nonhemolytic streptococci	1	2.9	1	0	0.0	-
Escherichia sp.	7	20.0	1	3	8.6	0
Aerobacter-Klebsiella	2	5.7	0	0	0.0	-
Paracolobactrum sp.	1	2.9	1	0	0.0	-
Bacteroides sp.	2	5.7	0	0	0.0	-
Other	6	17.1	0	2	5.7	0
None	16	45.7	0			

Table 71. Frequencies of Recovery of Organisms From Cultures of 29 Dirty Wounds at Operation

Organism	All recoveries			Recoveries involving only one organism		
	Number of times recovered	Frequency of recovery, percent	Number of times recovered from wounds that became infected (total:4)	Number of times recovered	Frequency of recovery, percent	Number of times recovered from wounds that became infected
Coag.-pos. staphylococci	4	13.8	2	2	6.9	1
Coag.-neg. staphylococci	2	6.9	1	0	0.0	-
Anaerobic streptococci	1	3.4	0	0	0.0	-
Escherichia sp.	4	13.8	0	1	3.4	0
Proteus sp.	1	3.4	0	1	3.4	0
Clostridium sp.	1	3.4	0	0	0.0	-
Bacteroides sp.	2	6.9	1	0	0.0	-
Other	5	17.2	1	1	3.4	-
None	17	58.6	1			

Table 72. Frequencies of Recovery of Organisms From Cultures of 824 Clean Wounds at Operation, by Postoperative Infection Status

Organism	Postoperatively infected (total:11)		Postoperatively uninfected (total:813)	
	Number of times recovered	Frequency of recovery, percent	Number of times recovered	Frequency of recovery, percent
Coag.-pos. staphylococci	2	18.2	10	1.2
Coag.-neg. staphylococci	2	18.2	86	10.6
Alpha-hemolytic streptococci	0	0.0	2	0.2
Beta-hemolytic streptococci	0	0.0	6	0.7
Nonhemolytic streptococci	0	0.0	24	3.0
Anaerobic streptococci	0	0.0	4	0.5
Escherichia sp.	0	0.0	10	1.2
Aerobacter-Klebsiella	0	0.0	5	0.6
Paracolobactrum sp.	0	0.0	5	0.6
Proteus sp.	0	0.0	3	0.4
Pseudomonas sp.	0	0.0	2	0.2
Other	3	27.3	116	14.3
Unidentified	0	0.0	1	0.1
None	5	45.5	569	70.0

Table 73. Frequencies of Recovery of Organisms From Cultures of 298 Clean-Contaminated Wounds at Operation, by Postoperative Infection Status

Organism	Postoperatively infected (total:12)		Postoperatively uninfected (total:286)	
	Number of times recovered	Frequency of recovery, percent	Number of times recovered	Frequency of recovery, percent
Coag.-pos. staphylococci	2	16.7	7	2.4
Coag.-neg. staphylococci	2	16.7	31	10.8
Alpha-hemolytic streptococci	1	8.3	4	1.4
Beta-hemolytic streptococci	1	8.3	3	1.0
Nonhemolytic streptococci	2	16.7	11	3.8
Anaerobic streptococci	0	0.0	4	1.4
Escherichia sp.	0	0.0	16	5.6
Aerobacter-Klebsiella	1	8.3	8	2.8
Paracolobactrum sp.	1	8.3	1	0.3
Proteus sp.	1	8.3	4	1.4
Clostridium sp.	0	0.0	2	0.7
Bacteroides sp.	0	0.0	1	0.3
Other	1	8.3	53	18.5
None	2	16.7	170	59.4

staphylococcus isolated at operation. *Proteus sp.*, alpha-hemolytic streptococci, and anaerobic streptococci were each recovered with a frequency greater than one per cent, the alpha-hemolytic streptococci occurring as the sole organisms three times.

Contaminated Wounds. A total of 35 contaminated wounds were cultured at operation (Table 70). *Escherichia sp.* were recovered from 20.0 per cent, coagulase-positive staphylococci from 11.4 per cent, coagulase-negative staphylococci from 8.6 per cent, and the *Aerobacter-Klebsiella* group and *Bacteroides sp.* each from 5.7 per cent. Other organisms listed were each isolated only once (an incidence of 2.9%). The coagulase-positive staphylococci were recovered as the sole organisms in three of the four cultures positive for this species.

Dirty Wounds. Table 71 lists the organisms recovered from the operative cultures of 29 dirty wounds, 17 (58.6%) of which

Table 74. Frequencies of Recovery of Organisms From Cultures of 35 Contaminated Wounds at Operation, by Postoperative Infection Status

Organism	Postoperatively infected (total:3)		Postoperatively uninfected (total:32)	
	Number of times recovered	Frequency of recovery, percent	Number of times recovered	Frequency of recovery, percent
Coag.-pos. staphylococci	2	66.7	2	6.2
Coag.-neg. staphylococci	0	0.0	3	9.4
Alpha-hemolytic streptococci	0	0.0	1	3.1
Beta-hemolytic streptococci	0	0.0	1	3.1
Nonhemolytic streptococci	1	33.3	0	0.0
Escherichia sp.	1	33.3	6	18.8
Aerobacter-Klebsiella	0	0.0	2	6.2
Paracolobactrum sp.	1	33.3	0	0.0
Bacteroides sp.	0	0.0	2	6.2
Other	0	0.0	6	18.8
None	0	0.0	16	50.0

Table 75. Frequencies of Recovery of Organisms From Cultures of 29 Dirty Wounds at Operation, by Postoperative Infection Status

Organism	Postoperatively infected (total: 4)		Postoperatively uninfected (total: 25)	
	Number of times recovered	Frequency of recovery, percent	Number of times recovered	Frequency of recovery, percent
Coag.-pos. staphylococci	2	50.0	2	8.0
Coag.-neg. staphylococci	1	25.0	1	4.0
Anaerobic streptococci	0	0.0	1	4.0
Escherichia sp.	0	0.0	4	16.0
Proteus sp.	0	0.0	1	4.0
Clostridium sp.	0	0.0	1	4.0
Bacteroides sp.	1	25.0	1	4.0
Other	1	25.0	4	16.0
None	1	25.0	16	64.0

were sterile. Coagulase-positive staphylococci and *Escherichia sp.* were each recovered from four cultures, each as the sole organisms in one instance.

Frequency of Organisms Recovered From Cultures by Wound Classification and Postoperative Infection Status. The organisms recovered from cultures of clean, clean-contaminated, contaminated, and dirty wounds at operation are listed in Tables 72–75, according to the presence or absence of postoperative infection. Several interesting trends emerged, for example, the frequency with which the enteric organisms were recovered from clean wounds that did not become infected and the complete lack of recovery at operation of those organisms from wounds that did become infected (although the number of wounds in the latter category is small, compared with the number of uninfected wounds). A variety of gram-negative organisms that were only infrequently found in personnel and on sedimentation plates do occur in the wounds just before closure with a frequency that suggests an endogenous or

Table 76. Frequencies of Recovery of Organisms From Cultures of All 1,186 Wounds at Operation, by Irradiation Status

Organism	Irradiated (total: 590)		Unirradiated (total: 596)	
	Number of times recovered	Frequency of recovery, percent	Number of times recovered	Frequency of recovery, percent
Coag.-pos. staphylococci	10	1.7	19	3.2
Coag.-neg. staphylococci	64	10.9	62	10.4
Alpha-hemolytic streptococci	4	0.7	4	0.7
Beta-hemolytic streptococci	6	1.0	5	0.8
Nonhemolytic streptococci	21	3.5	17	2.9
Anaerobic streptococci	2	0.3	7	1.2
Escherichia sp.	17	2.9	20	3.4
Aerobacter-Klebsiella	7	1.2	9	1.5
Paracolobactrum sp.	5	0.8	3	0.5
Proteus sp.	4	0.7	5	0.8
Pseudomonas sp.	1	0.2	1	0.2
Clostridium sp.	1	0.2	2	0.3
Bacteroides sp.	3	0.5	2	0.3
Other	60	10.1	124	20.8
Unidentified	0	0.0	1	0.2
None	420	71.2	359	60.2

Table 77. Frequencies of Recovery of Organisms From Cultures of 824 Clean Wounds at Operation, by Irradiation Status

Organism	Irradiated (total: 407)		Unirradiated (total: 417)	
	Number of times recovered	Frequency of recovery, percent	Number of times recovered	Frequency of recovery, percent
Coag.-pos. staphylococci	5	1.2	7	1.7
Coag.-neg. staphylococci	42	10.3	46	11.0
Alpha-hemolytic streptococci	1	0.2	1	0.2
Beta-hemolytic streptococci	3	0.7	3	0.7
Nonhemolytic streptococci	17	4.2	7	1.7
Anaerobic streptococci	0	0.0	4	1.0
Escherichia sp.	6	1.5	4	1.0
Aerobacter-Klebsiella	3	0.7	2	0.5
Paracolobactrum sp.	3	0.7	2	0.5
Proteus sp.	0	0.0	3	0.7
Pseudomonas sp.	1	0.2	1	0.2
Other	38	9.3	81	19.4
Unidentified	0	0.0	1	0.2
None	305	74.9	269	64.5

direct-contact source. A temporary bacteremia may be responsible for seeding the wound during the operative procedure.

Although the numbers of wounds decreased considerably for the different classifications from clean to dirty, an apparent shift in the incidence of certain genera was evident. The frequency of recovery of coagulase-positive staphylococci, for example, increased with the more obviously contaminated wounds, from 1.2 per cent in clean wounds that did not become infected to 8.0 per cent in dirty wounds that did not become infected. The same trend is apparent for other genera, for example, *Escherichia sp.*, which increased from a frequency of 1.2 per cent in clean wounds to 18.8 and 16.0 per cent in contaminated and dirty wounds, respectively.

Also of interest was the failure to recover the enteric organisms at operation from dirty wounds that did become infected;

Table 78. Frequencies of Recovery of Organisms From Cultures of 298 Clean-Contaminated Wounds at Operation, by Irradiation Status

Organism	Irradiated (total: 150)		Unirradiated (total: 148)	
	Number of times recovered	Frequency of recovery, percent	Number of times recovered	Frequency of recovery, percent
Coag.-pos. staphylococci	2	1.3	7	4.7
Coag.-neg. staphylococci	19	12.7	14	9.5
Alpha-hemolytic streptococci	3	2.0	2	1.4
Beta-hemolytic streptococci	2	1.3	2	1.4
Nonhemolytic streptococci	4	2.7	9	6.1
Anaerobic streptococci	2	1.3	2	1.4
Escherichia sp.	8	5.3	8	5.4
Aerobacter-Klebsiella	4	2.7	5	3.4
Paracolobactrum sp.	1	0.7	1	0.7
Proteus sp.	3	2.0	2	1.4
Clostridium sp.	1	0.7	1	0.7
Bacteroides sp.	0	0.0	1	0.7
Other	16	10.7	38	25.7
None	95	63.3	77	52.0

Table 79. Frequencies of Recovery of Organisms From Cultures of 35 Contaminated Wounds at Operation, by Irradiation Status

Organism	Irradiated (total: 16)		Unirradiated (total: 19)	
	Number of times recovered	Frequency of recovery, percent	Number of times recovered	Frequency of recovery, percent
Coag.-pos. staphylococci	1	6.2	3	15.8
Coag.-neg. staphylococci	1	6.2	2	10.5
Alpha-hemolytic streptococci	0	0.0	1	5.3
Beta-hemolytic streptococci	1	6.2	0	0.0
Nonhemolytic streptococci	0	0.0	1	5.3
Escherichia sp.	1	6.2	6	31.6
Aerobacter-Klebsiella	0	0.0	2	10.5
Paracolobactrum sp.	1	6.2	0	0.0
Bacteroides sp.	2	12.5	0	0.0
Other	2	12.5	4	21.1
None	11	68.8	5	26.3

here, however, the number of wounds may have been too small for the detection of low-prevalence organisms.

Effect of Ultraviolet Irradiation on Frequency of Organisms Recovered From Wounds. Table 76 compares the frequency of recovery of organisms from operative cultures of all classes of wounds on the basis of whether or not they were irradiated. As indicated above (Table 64), sterile cultures were significantly more common in irradiated wounds. Ultraviolet irradiation increased the frequency of sterile cultures by 11.0 per cent. There was also an apparent effect on the frequency of recovery of coagulase-positive staphylococci (3.2% from unirradiated and 1.7% from irradiated wounds), although the effects on recovery of other genera were less than 1.0 per cent.

Tables 77–80 indicate the frequencies with which organisms were recovered from irradiated and unirradiated wounds of the individual classifications. The frequency of recovery of coagulase-positive staphylococci was higher from unirradiated than from irradiated wounds for each classification. The effects on other genera were variable, and the relatively small numbers of wounds in each group make it difficult to assess the significance of any apparent differences.

Phage Patterns of *Staphylococcus aureus* Isolated From Wound Cultures. The phage types of *Staphylococcus aureus* and the frequency with which they were

Table 80. Frequencies of Recovery of Organisms From Cultures of 29 Dirty Wounds at Operation, by Irradiation Status

Organism	Irradiated (total: 17)		Unirradiated (total: 12)	
	Number of times recovered	Frequency of recovery, percent	Number of times recovered	Frequency of recovery, percent
Coag.-pos. staphylococci	2	11.8	2	16.7
Coag.-neg. staphylococci	2	11.8	0	0.0
Anaerobic streptococci	0	0.0	1	8.3
Escherichia sp.	2	11.8	2	16.7
Proteus sp.	1	5.9	0	0.0
Clostridium sp.	0	0.0	1	8.3
Bacteroides sp.	1	5.9	1	8.3
Other	4	23.5	1	8.3
None	9	52.9	8	66.7

Table 81. Phage Types of Staphylococcus aureus Recovered From Cultures of Wounds at Operation

Wound classification	Phage types of S. aureus	Number of times isolated	Number of wounds that developed postoperative infection
Clean	nontypable	10	1
	52,52A,80,81	1	0
	47,53,54,75,77	1	0
	VA-4,81	1	0
	53,77	1	0
	29	1	0
Clean-contaminated	nontypable	4	1
	47,53,54,77	1	0
	53,VA-4	1	0
	80,81	1	1
	52	1	0
Contaminated	nontypable	2	0
	80,81	1	1
	53,77	1	1
Dirty	nontypable	3	1
	52,52A,80,81	1	1

observed to occur in wounds just before closure are listed in Table 81. Of the 29 isolates, 19 (65.5%) were nontypable. The classical epidemic strain, 80,81, occurred in one clean-contaminated and one contaminated wound, each of which developed a postoperative infection. This strain was not manifest, however, in the postoperative drainage of either wound (Table 83). Phage type 52,52A,80,81 occurred in one clean and one dirty wound; only the dirty wound developed a postoperative infection. Phage type 53,77 was isolated from one clean and one contaminated wound; only the contaminated wound became infected. The remaining six strains isolated comprised phage patterns of Groups I, III, and Miscellaneous; none of the wounds from which they were isolated developed postoperative infection.

Comparison of Bacterial Flora at Time of Operation With Flora of Postoperative Drainage of Wounds That Developed Infection. Of 146 wounds cultured both at time of operation and postoperatively, 14 became infected. The organisms recovered from those wounds at operation and from their postoperative drainage are listed in Table 82.

Six of the 14 were clean wounds. There seems to be no correlation between the bacterial flora in those six wounds at operation and the flora of the postoperative wound drainage. In one instance a "nontypable" *S. aureus* was isolated both at operation and from the postoperative drainage, but use of an experimental phage indicated that they were different strains.

Of the eight nonclean wounds, there were two clean-contaminated wounds that yielded the same organism both at operation and postoperatively. *Paracolobactrum intermedium* was recovered from both cultures of one wound, and *Escherichia coli* from both cultures of the other. In neither case can it be said with certainty that the strain isolated from the postoperative culture was the same as that isolated from the wound at operation, because no serotyping or other definitive strain characterization was attempted.

Table 83 lists the bacterial flora recovered at time of operation and from postoperative drainage of the eight wounds that demonstrated an apparent persistence of specific organisms from time of operation through postoperative drainage but did not become infected. The first wound listed in the table is of particular interest because three different genera seemed to persist, although, as noted above, *strain* characterization was not attempted. The predominance of coagulase-negative staphylococci is also of interest.

The remaining 124 wounds (of the 146 cultured both at time of operation and postoperatively), none of which became infected, demonstrated no correlation between bacterial flora of operative cultures and postoperative cultures.

Discussion: The bacteriologic studies of the wound at time of operation confirmed the accepted impression discussed earlier in the monograph: as the likelihood of bacterial contamination of the operative wound increases, the postoperative infection rate increases. The frequency of sterile cultures of wounds taken just before closure progressively decreased, from clean to clean-

Table 82. Organisms Recovered at Operation and From Postoperative Drainage of Wounds That Became Infected

Wound classification		Organisms recovered	
		At operation	From postoperative wound drainage
Clean:	1	Staphylococcus aureus (nontypable)	Staphylococcus aureus (nontypable), beta-hemolytic Streptococcus, Bacteroides sp., Escherichia sp., Proteus sp., Staphylococcus epidermidis
	2	None	Staphylococcus aureus (53,77), Paracolobactrum sp., Staphylococcus epidermidis, Bacillus sp.
	3	Beta-hemolytic Streptococcus, Micrococcus, Sarcina	Staphylococcus aureus (80,81)
	4	Bacillus sp., Sarcina	Gaffkya sp., Staphylococcus epidermidis
	5	Staphylococcus epidermidis	Nonhemolytic Streptococcus, Bacillus sp.
	6	None	Staphylococcus aureus (nontypable), alpha-hemolytic Streptococcus
Clean-contaminated:			
	1	Staphylococcus aureus (80,81)	Pseudomonas aeruginosa
	2	Paracolobactrum intermedium	Paracolobactrum intermedium, Micrococcus sp., Bacillus sp.
	3	None	Nonhemolytic Streptococcus, Gaffkya sp., Micrococcus sp.
	4	None	Paracolobactrum
	5	Escherichia coli, nonhemolytic Streptococcus	Escherichia coli, Staphylococcus aureus (nontypable), Staphylococcus epidermidis
Contaminated:			
	1	Staphylococcus aureus (80,81)	Staphylococcus aureus (54,42D), Micrococcus sp., Staphylococcus epidermidis
	2	Staphylococcus epidermidis	Escherichia, Aerobacter-Klebsiella, nonhemolytic Streptococcus
Dirty:			
	1	Staphylococcus epidermidis, Micrococcus sp.	Staphylococcus aureus (nontypable), Proteus

contaminated and contaminated wounds. Wounds that yielded bacteria at the time of operation had a postoperative infection rate more than five times that for wounds that were sterile by culture; this relationship is apparent for each classification of wound (Table 65). The frequency of postoperative infection in wounds from which organisms were recovered increased significantly from clean to dirty wounds (Table 65), which probably indicates an increase in the degree of bacterial contamination with the increased incidence of gastrointestinal surgery. The progressively increasing frequency of recovery of *Escherichia sp.* from clean to contaminated wounds (Tables 68–70) tends to confirm this likelihood.

The comprehensiveness of the spectrum of bacterial species recovered from the wounds at the time of operation is surprising, especially for the clean wounds, of

Table 83. Organisms Recovered at Operation and From Postoperative Drainage of Clean Wounds That Did Not Become Infected

	Organisms recovered	
	At operation	From postoperative wound drainage
1	Beta-hemolytic Streptococcus, Proteus sp., Bacillus sp.	Beta-hemolytic Streptococcus, Proteus sp., Bacillus sp., Bacteroids sp.
2	Paracolobactrum sp.	Paracolobactrum sp.
3	Staphylococcus epidermidis	Staphylococcus epidermidis, Staphylococcus aureus (nontypable), Escherichia sp., nonhemolytic Streptococcus
4	Staphylococcus epidermidis	Staphylococcus epidermidis, Bacillus sp.
5	Staphylococcus epidermidis, Micrococcus sp.	Staphylococcus epidermidis
6	Staphylococcus epidermidis	Staphylococcus epidermidis
7	Staphylococcus epidermidis	Staphylococcus epidermidis
8	Bacillus sp.	Bacillus sp., Staphylococcus aureus (nontypable), Bacteroides sp.

which 30 per cent yielded at least one species of micro-organism (Table 68). The occurrence in clean wounds of the gram-negative bacilli and other genera associated with the intestinal flora is thought-provoking, and the frequency with which they were isolated in pure culture suggests an endogenous source. The frequency with which staphylococci were recovered is somewhat lower than reported by others. Ives and Hirshfeld (1938) cultured the peritoneum, fascia, and skin at the close of operation and reported staphylococci cultured from 63, 76, and 100 per cent of each, respectively.

Postoperative infection occurred with the highest frequency in wounds that yielded coagulase-positive staphylococci at the time of operation (Table 66); 27.6 per cent (8/29) of the wounds known to harbor coagulase-positive staphylococci at the time of operation developed postoperative infections. They were recovered as the sole organisms from 19 wounds, of which five (or 26.3%) developed postoperative infections. As discussed earlier, however, it was not conclusively demonstrated in these studies that the organisms associated with the postoperative infections were the same as those isolated from wounds at the time of operation.

It must be kept in mind that the methods of sampling wounds to detect micro-organisms are of the utmost importance in any epidemiological investigation of wound infections. The method chosen for the studies discussed above was considered easy for the operating team to use and readily standardized. Culturing the entire volume of aspirated saline used for sampling the wound increases the chances of recovery of organisms, although some bacteria in the wound may be missed because of the small numbers in which they are present in the wound at a given time.

Bacteriologic Survey of Postoperative Wound Drainage

As noted at the beginning of this chapter, all draining wounds in each hospital were cultured every 3 days until there was clinical evidence of wound infection or until drainage ceased. This effort yielded 1,931 cultures of 1,395 wounds, and in this section analysis is confined to the first culture of each wound. Considering the protocol requirements of culturing postoperatively all wounds that manifest any sign of infection or drainage, the percentage of wounds cultured for each classification is about what one might anticipate, generally increasing with wound classification, from clean to dirty. The distribution of the wounds cultured, by classification of operation and by hospital, is indicated in Table 84. The majority (55.8%) of the wounds cultured were *clean* wounds, 29.5 per cent were *clean-contaminated* wounds, 6.8 per cent were *contaminated* wounds, and 7.9 per cent were *dirty* wounds.

Frequency of Organisms Recovered From Postoperative Wound Drainage. The frequency of organisms recovered from all wounds is indicated in Table 85. No organisms were recovered from 319 (23.0%). From the 1,388 wounds cultured, the most frequently isolated organisms were the coagulase-negative staphylococci, which were recovered from 450 (32.4%) of the wounds. Some organisms recovered are not specified

Table 84. Distribution of Postoperative Wound Drainage Cultures, by Wound Classification and Hospital

Wound classification	Wounds cultured/total wounds — Hospital 1	2	3	4	5	Totals
Clean	63/1833 (3.4%)	265/2633 (10.1%)	101/1923 (5.3%)	105/1404 (7.5%)	240/3897 (6.2%)	774/11690 (6.6%)
Clean-contaminated	57/428 (13.3%)	65/185 (35.1%)	69/448 (15.4%)	111/681 (16.3%)	107/847 (12.6%)	409/2589 (15.8%)
Contaminated	9/31 (29.0%)	6/53 (11.3%)	8/115 (7.0%)	31/249 (12.4%)	41/233 (17.6%)	95/681 (14.0%)
Dirty	10/35 (28.6%)	17/91 (18.7%)	11/69 (15.9%)	45/230 (19.6%)	27/156 (17.3%)	110/581 (18.9%)
Totals	139/2327 (6.0%)	353/2962 (11.9%)	189/2555 (7.4%)	292/2564 (11.4%)	415/5133 (8.1%)	1388/15541* (8.9%)

*72 wounds were of unknown classification; 7 of these had wound-drainage cultures.

in the table: *Micrococcus sp., Sarcina sp., Gaffkya sp., Bacillus sp., Serratia sp., Corynebacterium sp., Achromobacter sp., Alcaligenes sp., Diplococcus, Neisseria sp.*, yeast, and fungi.

The enteric organisms were encountered with a frequency second only to that of the staphylococci, which is interesting in view of the infrequency of their identification in the sedimentation plates (Table 59). However, the enteric bacteria are likely to arrive in the wounds by means other than aerial fallout; e.g., Hallpike, MacKeith, and Evans (1961) reported a *coliform bacillus* isolated from the hands of an operator, and the likelihood of an endogenous source is often obvious.

Table D-2 is a more detailed list of the frequencies of recovery of organisms from the cultures of each hospital. The frequency of recovery of coagulase-positive staphylococci was comparable among all institutions, ranging from 13.9 to 27.4 per cent, with a mean frequency of 19.5 per cent. Most of the other organisms indicated were recovered with more variable frequencies. Beta-hemolytic streptococci were recovered 15 times at Hospital 2, but not at all at Hospital 1. On the other hand, Hospital 1 reported by far the highest frequency (23.7%) of recovery of *Escherichia sp.* Attempts to correlate the frequency of recovery of specific organisms with over-all infection rates at the individual hospitals do not seem to suggest a pattern of any significance.

Relationship of Recovery of Various Organisms and Postoperative Infection. Analysis of the frequencies of recovery of organisms from postoperatively infected and uninfected wounds (Table 86) reveals that staphylococci remain the most important organisms found in postoperative wound infection. Of the 1,388 wounds cultured, 390 developed postoperative infections; coagulase-positive staphylococci were

Table 85. Frequencies of Recovery of Organisms From Cultures of 1,388 Wound Drainages, Combined Hospitals

Organism	Number of times recovered	Frequency of recovery, percent
Coag.-pos. staphylococci	268	19.3
Coag.-neg. staphylococci	450	32.4
Alpha-hemolytic streptococci	36	2.6
Beta-hemolytic streptococci	33	2.4
Nonhemolytic streptococci	122	8.8
Anaerobic streptococci	6	0.4
Escherichia sp.	209	15.1
Aerobacter-Klebsiella	87	6.3
Paracolobactrum sp.	62	4.5
Proteus sp.	110	7.9
Pseudomonas sp.	112	8.1
Clostridium sp.	9	0.6
Bacteroides sp.	18	1.3
Other	289	20.8
Unidentified	10	0.7
None	319	23.0

isolated from 122 (31.3%) of the infected wounds and from 146 (14.6%) of the clinically uninfected wounds. Coagulase-negative staphylococci were recovered from 123 (31.5%) of the infected wounds, and the enteric gram-negative bacteria, *Escherichia sp.*, *Proteus sp.*, and *Pseudomonas sp.*, occurred with incidences of 22.3, 13.3, and 13.1 per cent, respectively.

Although the over-all data identify the coagulase-positive staphylococcus as the single most important organism in postoperative wound infections, inspection of Table D-3 reveals a range of prevalence of this organism in infected wounds from 23.2 per cent at Hospital 5 to 47.2 per cent at Hospital 4. These two hospitals cultured 151 and 36 infected wounds, respectively. Considering the variations in the over-all wound infection rates among the individual hospitals, it is apparent that the problem of postoperative infection with coagulase-positive staphylococcus may likewise be extremely variable from hospital to hospital. Hospital 4, with the lowest over-all infection rate, 3.0 per cent, seems to have had the greatest problem with *Staphylococcus aureus*. Hospitals 1, 2 and 3, which reported comparable frequencies of recovery of coagulase-positive staphylococci from postoperative drainage of infected wounds (ranging from 32.1 to 35.6%), reported over-all infection rates ranging from 4.8 to 11.7 per cent. Williams, McDonald, and Blowers (1960), in a cooperative study involving 21 hospitals, reported S. *aureus* to occur in 60 per cent of postoperatively infected wounds and in 9 per cent of "healthy" wounds. Barnes, Behringer, Wheelock, and Wilkins (1961) reported a frequency of recovery of S. *aureus* of 65 per cent in infected wounds following hysterectomies and herniorrhaphies. Hart (1937) and Henderson (1961) reported S. *aureus* to be the causative organism in 90 and 70 per cent of postoperatively infected wounds, respectively. Forbes (1961) reported an over-all infection rate by S. *aureus* of 3.3 per cent in over 6,000 surgical wounds.

Variations in incidences of recovery of other organisms are worthy of comment. The frequency of occurrence of *Pseudomonas sp.* in infected wounds ranged from

Table 86. Frequencies of Recovery of Organisms From Cultures of Postoperative Drainage of All Wounds, by Postoperative Infection Status, Combined Hospitals

Organism	Recovered from infected wounds (total: 390)		Recovered from uninfected wounds (total: 998)	
	Number of times recovered	Frequency of recovery, percent	Number of times recovered	Frequency of recovery, percent
Coag.-pos. staphylococci	122	31.3	146	14.6
Coag.-neg. staphylococci	123	31.5	327	32.8
Alpha-hemolytic streptococci	14	3.6	22	2.2
Beta-hemolytic streptococci	8	2.1	25	2.5
Nonhemolytic streptococci	38	9.7	84	8.4
Anaerobic streptococci	1	0.3	5	0.5
Escherichia sp.	87	22.3	122	12.2
Aerobacter-Klebsiella	34	8.7	53	5.3
Paracolobactrum sp.	22	5.6	40	4.0
Proteus sp.	52	13.3	58	5.8
Pseudomonas sp.	51	13.1	61	6.1
Clostridium sp.	5	1.3	4	0.4
Bacteroides sp.	7	1.8	11	1.1
Other	72	18.5	217	21.7
Unidentified	3	0.8	7	0.7
None	36	9.2	283	28.4

Table 87. Frequencies of Recovery of Organisms From Cultures of Postoperative Drainage of Wounds That Became Infected, by Wound Classification, Combined Hospitals

Organism	Frequency of recovery							
	Clean (total:181)		Clean-contaminated (total:123)		Contaminated (total:37)		Dirty (total:49)	
	Number of times recovered	Frequency of recovery, percent	Number of times recovered	Frequency of recovery, percent	Number of times recovered	Frequency of recovery, percent	Number of times recovered	Frequency of recovery, percent
Coag.-pos. staphylococci	61	33.7	31	25.2	14	37.8	16	32.7
Coag.-neg. staphylococci	65	35.9	40	32.5	10	27.0	8	16.3
Alpha-hemolytic streptococci	7	3.9	3	2.4	2	5.4	2	4.1
Beta-hemolytic streptococci	6	3.3	1	0.8	0	0.0	1	2.0
Nonhemolytic streptococci	15	8.3	11	8.9	5	13.5	7	14.3
Anaerobic streptococci	0	0.0	0	0.0	0	0.0	1	2.0
Escherichia sp.	29	16.0	28	22.8	15	40.5	15	30.6
Aerobacter-Klebsiella	15	8.3	16	13.0	1	2.7	2	4.1
Paracolobactrum sp.	9	5.0	5	4.1	5	13.5	3	6.1
Proteus sp.	20	11.0	19	15.4	5	13.5	8	16.3
Pseudomonas sp.	21	11.6	20	16.3	4	10.8	6	12.2
Clostridium sp	2	1.1	3	2.4	0	0.0	0	0.0
Bacteroides sp.	4	2.2	0	0.0	2	5.4	1	2.0
Other	23	12.7	34	27.6	9	24.3	6	12.2
Unidentified	2	1.1	1	0.8	0	0.0	0	0.0
None	20	11.0	7	5.7	3	8.1	6	12.2

2.8 per cent (Hospital 4) to 20.8 per cent (Hospital 2). There is no apparent correlation, however, with over-all infection rates. A similar picture is presented by *Proteus sp.*, *Escherichia sp.*, beta-hemolytic streptococci, and coagulase-negative staphylococci, the frequency of the latter ranging from 7.5 to 40.4 per cent.

Table 86 also includes the organisms recovered from postoperative drainage of wounds that did not become infected. It is of interest to note the frequency with which a variety of bacteria may be cultured from wound drainage with no clinical manifestations of infection. The frequency of recovery of coagulase-positive staphylococci from 998 such wounds cultured was 14.6 per cent, slightly less than half its frequency of recovery from definitely infected wounds. This trend is also apparent with *Escherichia sp.*, *Proteus sp.*, and *Pseudomonas sp.* One may conclude from these data that fewer than half the wounds harboring these organisms postoperatively actually develop frank clinical infections. Only 28.4 per cent of these wounds were sterile by culture. Furthermore, there is little doubt that more critical and refined methods of sampling operative wounds might have resulted in the

Table 88. Frequencies of Recovery of Organisms From Cultures of Postoperative Drainage of Wounds That Did Not Become Infected, by Wound Classification, Combined Hospitals

Organism	Frequency of recovery							
	Clean (total:593)		Clean-contaminated (total:286)		Contaminated (total:58)		Dirty (total:61)	
	Number of times recovered	Frequency of recovery, percent	Number of times recovered	Frequency of recovery, percent	Number of times recovered	Frequency of recovery, percent	Number of times recovered	Frequency of recovery, percent
Coag.-pos. staphylococci	76	12.8	47	16.4	15	25.9	8	13.1
Coag.-neg. staphylococci	215	36.3	81	28.3	20	34.5	11	18.0
Alpha-hemolytic streptococci	13	2.2	7	2.4	1	1.7	1	1.6
Beta-hemolytic streptococci	14	2.4	7	2.4	2	3.4	2	3.3
Nonhemolytic streptococci	42	7.1	23	8.0	9	15.5	5	8.2
Anaerobic streptococci	4	0.7	1	0.3	0	0.0	0	0.0
Escherichia sp.	49	8.3	40	14.0	11	19.0	22	36.1
Aerobacter-Klebsiella	28	4.7	14	4.9	8	13.8	3	4.9
Paracolobactrum sp.	17	2.9	15	5.2	3	5.2	5	8.2
Proteus sp.	27	4.6	20	7.0	5	8.6	6	9.8
Pseudomonas sp.	20	3.4	27	9.4	5	8.6	9	14.8
Clostridium sp.	1	0.2	3	1.0	0	0.0	0	0.0
Bacteroides sp.	8	1.3	1	0.3	0	0.0	2	3.3
Other	120	20.2	72	25.2	7	12.1	18	29.5
Unidentified	3	0.5	4	1.4	0	0.0	0	0.0
None	194	32.7	66	23.1	12	20.7	11	18.0

Table 89. Frequencies of Recovery of Organisms From Cultures of Postoperative Drainage of All Wounds, by Irradiation Status, Combined Hospitals

Organism	All wounds: Irradiated (total:689) Number of times recovered	All wounds: Irradiated (total:689) Frequency of recovery, percent	All wounds: Unirradiated (total:699) Number of times recovered	All wounds: Unirradiated (total:699) Frequency of recovery, percent	Wounds that became infected: Irradiated (total:197) Number of times recovered	Wounds that became infected: Irradiated (total:197) Frequency of recovery, percent	Wounds that became infected: Unirradiated (total:193) Number of times recovered	Wounds that became infected: Unirradiated (total:193) Frequency of recovery, percent	Wounds that did not become infected: Irradiated (total:492) Number of times recovered	Wounds that did not become infected: Irradiated (total:492) Frequency of recovery, percent	Wounds that did not become infected: Unirradiated (total:506) Number of times recovered	Wounds that did not become infected: Unirradiated (total:506) Frequency of recovery, percent
Coag.-pos. staphylococci	126	18.3	142	20.3	50	25.4	72	37.3	76	15.4	70	13.8
Coag.-neg. staphylococci	227	32.9	223	31.9	70	35.5	53	27.5	157	31.9	170	33.6
Alpha-hemolytic streptococci	18	2.6	18	2.6	8	4.1	6	3.1	10	2.0	12	2.4
Beta-hemolytic streptococci	18	2.6	15	2.1	5	2.5	3	1.6	13	2.6	12	2.4
Nonhemolytic streptococci	59	8.6	63	9.0	20	10.2	18	9.3	39	7.9	45	8.9
Anaerobic streptococci	5	0.7	1	0.1	1	0.5	0	0.0	4	0.8	1	0.2
Escherichia sp.	110	16.0	99	14.2	44	22.3	43	22.3	66	13.4	56	11.1
Aerobacter-Klebsiella	43	6.2	44	6.3	15	7.6	19	9.8	28	5.7	25	4.9
Paracolobactrum sp.	30	4.4	32	4.6	13	6.6	9	4.7	17	3.5	23	4.5
Proteus sp.	60	8.7	50	7.2	34	17.3	18	9.3	26	5.3	32	6.3
Pseudomonas sp.	56	8.1	56	8.0	23	11.7	28	14.5	33	6.7	28	5.5
Clostridium sp.	7	1.0	2	0.3	5	2.5	0	0.0	2	0.4	2	0.4
Bacteroides sp.	13	1.9	5	0.7	5	2.5	2	1.0	8	1.6	3	0.6
Other	150	21.8	139	19.9	42	21.3	30	15.5	108	22.0	109	21.5
Unidentified	6	0.9	4	0.6	1	0.5	2	1.0	5	1.0	2	0.4
None	160	23.2	159	22.7	18	9.1	18	9.3	142	28.9	141	27.9

recovery of still more organisms from the clinically uninfected wounds.

Relationship of Recovery of Various Organisms and Wound Classification. Table 87 lists by wound classification the frequencies of recovery of organisms from postoperative cultures of wounds (and drains) that developed clinical infections. The organism most frequently recovered from clean wounds that became infected was the coagulase-negative staphylococcus, occurring in 35.9 per cent of such wounds. But it is interesting to note that the known pathogen most frequently recovered from clean wounds that became infected was the coagulase-positive staphylococcus, which occurred with a frequency of 33.7 per cent, that is, almost as often as the coagulase-negative. The coagulase-negative staphylococci were recovered with decreasing frequency, from clean to dirty wounds, although the relatively small numbers of the latter wounds make it difficult to assess the significance. *Escherichia sp.* tended to increase in frequency of recovery, from clean to contaminated wounds, as did the nonhemolytic streptococci, which probably reflects the increased incidence of gastro-intestinal surgery from the clean to the dirty classification. Little difference is apparent in the frequencies of recovery of the other genera related to the different categories of wounds. In Tables D-10–D-13, these data are broken down by individual hospital. Similar variations in the frequencies of recovery of organisms from wounds that did not become infected can be seen in Table 88.

It is of interest to note from Tables 87 and 88 that, of 137 clean wounds that yielded coagulase-positive staphylococci, 61 (44.5%) showed clinical signs of infection, whereas, of 280 clean wounds that yielded coagulase-negative staphylococci, only 65 (23.2%) developed infections. The likelihood of infection in draining wounds from which coagulase-positive staphylococci are recovered is highest for dirty

Table 90. Frequencies of Recovery of Organisms From Cultures of Postoperative Drainage of Clean Wounds That Became Infected, by Irradiation Status, Combined Hospitals

Organism	Irradiated (total: 89)		Unirradiated (total: 92)	
	Number of times recovered	Frequency of recovery, percent	Number of times recovered	Frequency of recovery, percent
Coag.-pos. staphylococci	23	25.8	38	41.3
Coag.-neg. staphylococci	43	48.3	22	23.9
Alpha-hemolytic streptococci	5	5.6	2	2.2
Beta-hemolytic streptococci	5	5.6	1	1.1
Nonhemolytic streptococci	6	6.7	9	9.8
Anaerobic streptococci	0	0.0	0	0.0
Escherichia sp.	13	14.6	16	17.4
Aerobacter-Klebsiella	7	7.9	8	8.7
Paracolobactrum sp.	7	7.9	2	2.2
Proteus sp.	15	16.9	5	5.4
Pseudomonas sp.	9	10.1	12	13.0
Clostridium sp.	2	2.2	0	0.0
Bacteroides sp.	3	3.4	1	1.1
Other	14	15.7	9	9.8
Unidentified	1	1.1	1	1.1
None	9	10.1	11	12.0

wounds. Of 78 clean-contaminated, 29 contaminated, and 24 dirty wounds from which these organisms were recovered, 39.7, 48.3, and 66.7 per cent, respectively, developed clinical signs of infection. In Tables D-14–D-17, these data concerning uninfected wounds are divided by individual hospital.

Relationship of Recovery of Various Organisms from Drainage and Ultraviolet Irradiation. Ultraviolet irradiation of the operating room had no apparent effect on the frequency of recovery of various organisms from postoperative wound drainage, if all wounds are considered together, whether or not they became infected (Table 89). Of the 1,388 wounds cultured, 689 (49.6%) were irradiated and 699 were not irradiated. The incidence of sterile postoperative cultures was approximately the same for each group.

Table 91. Frequencies of Recovery of Organisms From Cultures of Postoperative Drainage of Clean-Contaminated Wounds That Became Infected, by Irradiation Status, Combined Hospitals

Organism	Irradiated (total: 62)		Unirradiated (total: 61)	
	Number of times recovered	Frequency of recovery, percent	Number of times recovered	Frequency of recovery, percent
Coag.-pos. staphylococci	13	21.0	18	30.0
Coag.-neg. staphylococci	20	32.3	20	32.8
Alpha-hemolytic streptococci	1	1.6	2	3.3
Beta-hemolytic streptococci	0	0.0	1	1.6
Nonhemolytic streptococci	5	8.1	6	9.8
Anaerobic streptococci	0	0.0	0	0.0
Escherichia sp.	16	25.8	12	19.7
Aerobacter-Klebsiella	7	11.3	9	14.8
Paracolobactrum sp.	2	3.2	3	4.9
Proteus sp.	12	19.4	7	11.5
Pseudomonas sp.	8	12.9	12	19.7
Clostridium sp.	3	4.8	0	0.0
Bacteroides sp.	0	0.0	0	0.0
Other	20	32.3	14	23.0
Unidentified	0	0.0	1	1.6
None	4	6.5	3	4.9

Table 92. Frequencies of Recovery of Organisms From Cultures of Postoperative Drainage of Contaminated Wounds That Became Infected, by Irradiation Status, Combined Hospitals

Organism	Irradiated (total: 18)		Unirradiated (total: 19)	
	Number of times recovered	Frequency of recovery, percent	Number of times recovered	Frequency of recovery, percent
Coag.-pos. staphylococci	7	38.9	7	36.8
Coag.-neg. staphylococci	3	16.7	7	36.8
Alpha-hemolytic streptococci	1	5.6	1	5.3
Nonhemolytic streptococci	4	22.2	1	5.3
Escherichia sp.	8	44.4	7	36.8
Aerobacter-Klebsiella	1	5.6	0	0.0
Paracolobactrum sp.	2	11.1	3	15.8
Proteus sp.	3	16.7	2	10.5
Pseudomonas sp.	1	5.6	3	15.8
Bacteroides sp.	1	5.6	1	5.3
Other	4	22.2	5	26.3
None	1	5.6	2	10.5

There were no significant differences in the frequencies of recovery of any of the indicated organisms from the two groups of wounds. These data are divided by individual hospital in Table D-4. The results vary among hospitals, with the frequency of sterile postoperative cultures of the unirradiated wounds ranging from 7.0 to 35.6 per cent, and of the irradiated wounds, from 7.4 to 41.9 per cent. The effect of ultraviolet irradiation on the frequency of recovery of coagulase-positive staphlococci ranged from a 14.9 per cent decrease (Hospital 3) to a 7.7 per cent increase (Hospital 4). Although the significance is not clear, it is interesting to note that Hospital 3, with an over-all infection rate of 11.7 per cent, reported a decrease of 14.9 per cent in the frequency of recovery of these organisms in irradiated wounds, whereas Hospital 4, with an over-all infection rate of 3.0 per cent, reported an increase of 7.7 per cent. Similar variations in apparent effects of irradiation can be seen for a number of other organisms listed in Table D-4.

Table 89 also lists the frequencies of recovery of the various genera of bacteria from cultures of postoperative drainage of wounds that did and did not become infected. Coagulase-positive staphylococci were recovered from 25.4 per cent of the irradiated wounds with clinical infection and 37.3 per cent of the unirradiated. For other organisms frequently recovered the corresponding percentages (Table 89) favor now one and now the other treatment group.

Attention is again called to the frequency with which the variety of bacteria were recovered from postoperative drainage of wounds that did *not* become infected. Each organism listed was recovered at least once from such wounds.

The apparent effects of ultraviolet irradiation on the incidence of recovery of organisms from clean, clean-contaminated, contaminated, and dirty wounds that developed postoperative infection are variable, as indicated in Tables 90–93. The relatively small numbers of wounds for each classification make it difficult to assess the significance of differences in frequencies of recovery, but certain trends are suggested that do agree with the results discussed above. In clean wounds there is a decreased frequency of recovery of coagulase-positive staphylococci from irradiated wounds and an increased frequency of recovery of coagulase-negative staphylococci, *Proteus sp.*, and other organisms; however, the significance of this trend is not under-

Table 93. Frequencies of Recovery of Organisms From Cultures of Postoperative Drainage of Dirty Wounds That Became Infected, by Irradiation Status, Combined Hospitals

Organism	Irradiated (total: 28)		Unirradiated (total: 21)	
	Number of times recovered	Frequency of recovery, percent	Number of times recovered	Frequency of recovery, percent
Coag.-pos. staphylococci	7	25.0	9	42.9
Coag.-neg. staphylococci	4	14.3	4	19.0
Alpha-hemolytic streptococci	1	3.6	1	4.8
Beta-hemolytic streptococci	0	0.0	1	4.8
Nonhemolytic streptococci	5	17.9	2	9.5
Anaerobic streptococci	1	3.6	0	0.0
Escherichia sp.	7	25.0	8	38.1
Aerobacter-Klebsiella	0	0.0	2	9.5
Paracolobactrum sp.	2	7.1	1	4.8
Proteus sp.	4	14.3	4	19.0
Pseudomonas sp.	5	17.9	1	4.8
Bacteroides sp.	1	3.6	0	0.0
Other	4	14.3	2	9.5
Unidentified	0	0.0	0	0.0
None	4	14.3	2	9.5

stood. These data, listed by individual hospital, are found in Tables D-18–D-21.

Tables 94–97 list the frequencies of recovery of organisms from drainage of irradiated and unirradiated clean, clean-contaminated, contaminated, and dirty wounds, respectively, that did not develop infection. There are no apparent significant differences that suggest an effect of ultraviolet irradiation. These data, as well as those in Tables D-22–D-25, which list the frequencies of recovery by individual hospital, do point out again the wide variety of bacteria recovered from wounds that manifested no clinical signs of infection.

Phage Patterns of Coagulase-Positive Staphylococci Recovered From Postoperative Wound Drainage. A total of 334

Table 94. Frequencies of Recovery of Organisms From Cultures of Postoperative Drainage of Clean Wounds that Did Not Become Infected, by Irradiation Status, Combined Hospitals

Organism	Irradiated (total: 306)		Unirradiated (total: 287)	
	Number of times recovered	Frequency of recovery, percent	Number of times recovered	Frequency of recovery, percent
Coag.-pos. staphylococci	38	12.4	38	13.2
Coag.-neg. staphylococci	104	34.0	111	38.7
Alpha-hemolytic streptococci	6	2.0	7	2.4
Beta-hemolytic streptococci	8	2.6	6	2.1
Nonhemolytic streptococci	22	7.2	20	7.0
Anaerobic streptococci	3	1.0	1	0.3
Escherichia sp.	28	9.2	21	7.3
Aerobacter-Klebsiella	16	5.2	12	4.2
Paracolobactrum sp.	7	2.3	10	3.5
Proteus sp.	10	3.3	17	5.9
Pseudomonas sp.	10	3.3	10	3.5
Clostridium sp.	0	0.0	1	0.3
Bacteroides sp.	5	1.6	3	1.0
Other	70	22.9	50	17.4
Unidentified	3	1.0	0	0.0
None	102	33.3	92	32.1

Table 95. Frequencies of Recovery of Organisms From Cultures of Postoperative Drainage of Clean-Contaminated Wounds That Did Not Become Infected, by Irradiation Status, Combined Hospitals

Organism	Irradiated (total:127)		Unirradiated (total:159)	
	Number of times recovered	Frequency of recovery, percent	Number of times recovered	Frequency of recovery, percent
Coag.-pos. staphylococci	23	18.1	24	15.1
Coag.-neg. staphylococci	33	26.0	48	30.2
Alpha-hemolytic streptococci	3	2.4	4	2.5
Beta-hemolytic streptococci	3	2.4	4	2.5
Nonhemolytic streptococci	11	8.7	17	10.7
Anaerobic streptococci	1	0.8	0	0.0
Escherichia sp.	21	16.5	19	11.9
Aerobacter-Klebsiella	7	5.5	7	4.4
Paracolobactrum sp.	6	4.7	9	5.7
Proteus sp.	10	7.9	10	6.3
Pseudomonas sp.	17	13.4	10	6.3
Clostridium sp.	2	1.6	1	0.6
Bacteroides sp.	1	0.8	0	0.0
Other	23	18.1	49	30.8
Unidentified	2	1.6	2	1.3
None	32	25.2	34	21.4

coagulase-positive staphylococci were recovered from the 1,931 cultures of the 1,395 draining wounds that were cultured. Of these, 185 (55.4%) were nontypable with the Standard International Series of bacteriophage (Appendix C). Table 98 lists all the phage patterns reported by the combined hospitals from all categories of wounds and all cultures. Phage pattern 80,81 was the only one that occurred with a significant frequency (7.8% of all isolates tested and 17.4% of the typable strains). A total of 60 different phage patterns were reported, with the greater number falling within phage Group III.

Discussion: The recovery of coagulase-positive staphylococci from 31.3 per cent of the postoperatively infected wounds cultured (Table 86) emphasizes the current importance of this micrococcus, which was first described to occur in acute abscesses by Alexander Ogston, in 1880.

Table 96. Frequencies of Recovery of Organisms From Cultures of Postoperative Drainage of Contaminated Wounds That Did Not Become Infected, by Irradiation Status, Combined Hospitals

Organism	Irradiated (total:29)		Unirradiated (total:29)	
	Number of times recovered	Frequency of recovery, percent	Number of times recovered	Frequency of recovery, percent
Coag.-pos. staphylococci	9	31.0	6	20.7
Coag.-neg. staphylococci	15	51.7	5	17.2
Alpha-hemolytic streptococci	1	3.4	0	0.0
Beta-hemolytic streptococci	1	3.4	1	3.4
Nonhemolytic streptococci	4	13.8	5	17.2
Escherichia sp.	6	20.7	5	17.2
Aerobacter-Klebsiella	4	13.8	4	13.8
Paracolobactrum sp.	3	10.3	0	0.0
Proteus sp.	4	13.8	1	3.4
Pseudomonas sp.	2	6.9	3	10.3
Other	4	13.8	3	10.3
None	4	13.8	8	27.6

Table 97. Frequencies of Recovery of Organisms From Cultures of Postoperative Drainage of Dirty Wounds That Did Not Become Infected, by Irradiation Status, Combined Hospitals

Organism	Irradiated (total:30)		Unirradiated (total:31)	
	Number of times recovered	Frequency of recovery, percent	Number of times recovered	Frequency of recovery, percent
Coag.-pos. staphylococci	6	20.0	2	6.5
Coag.-neg. staphylococci	5	16.7	6	19.4
Alpha-hemolytic streptococci	0	0.0	1	3.2
Beta-hemolytic streptococci	1	3.3	1	3.2
Nonhemolytic streptococci	2	6.7	3	9.7
Escherichia sp.	11	36.7	11	35.5
Aerobacter-Klebsiella	1	3.3	2	6.5
Paracolobactrum sp.	1	3.3	4	12.9
Proteus sp.	2	6.7	4	12.9
Pseudomonas sp.	4	13.3	5	16.1
Bacteroides sp.	2	6.7	0	0.0
Other	11	36.7	7	22.6
None	4	13.3	7	22.6

Since then, the literature on staphylococcal wound sepsis has become voluminous. Beginning in 1900, the staphylococcus has been described as the "commonest," the "usual," the "most frequently found," and the "most common of infecting bacteria," associated with postoperative wound sepsis of operative as well as of accidental wounds. The impression that the incidence of postoperative infections due to the staphylococcus has progressively increased over the years is difficult to confirm by a review of the literature. Included in the reports of staphylococcal wound infections are those of Melchior and Lubinski (1923); Eliason and McLaughlin (1934); Hart (1937); Ives and Hirshfeld (1938); Cairns (1939); Miles, Schwabacher, Cunliffe, Ross, Spooner, Pilcher, and Wright (1940); Pulaski, Meleney, and Spaeth (1941); deWaal (1943); Caswell, Schreck, and Burnett (1960); Williams, McDonald, and Blowers (1960); Forbes (1961); Henderson (1961); and Rocha (1962). Barnes, Behringer, Wheelock, and Wilkins (1961), in a review of 16,000 operative procedures over a period of 20 years, reported no upward or downward trend in the incidence of postoperative sepsis and refute the claim that staphylococcal infections have become more prevalent in recent years.

The importance of aseptic and general operative technic in preventing postoperative wound infection has long been appreciated and is currently being called to attention by numerous authors who have realized the tendency to substitute antibiotic prophylaxis and chemotherapy for basic surgical principles (Freeman, 1925; Eliason and McLaughlin, 1934; Newell, 1934; Babcock, 1937; Elkin, 1940; Kinsella, 1944; Stephen, 1944; Howe, 1956, 1958; Altemeier, 1958; McDowell, 1959; Bernard and Cole, 1962). It seems more likely that the increasing problem of staphylococcal infections is a result, not of the increasing "virulence" or incidence of staphylococci in wounds, but of the impact that antibiotic therapy had on surgeons and the emergence of antibiotic-resistant strains resulting from the indiscriminate use of these agents (Altemeier, 1958). The facts that coagulase-positive staphylococci were recovered from 14.6 per cent of the drainages of wounds that did not become infected and that only 28.4 per cent of those wounds (i.e., those uninfected

wounds) were sterile by culture (Table 86) lend support to this impression.

To compound the difficulties met in attempts to resolve this question from the literature, various methods have been employed to identify staphylococci. A strain of *Staphylococcus aureus,* identified today by coagulase activity and fermentation of mannitol (Bergey's Manual of Determinative Bacteriology, 7th Edition, 1957), would not necessarily have been identified as this species before 1957, and *vice versa.* The 6th Edition of Bergey's Manual (1948) described *Micrococcus pyogenes* var. *aureus* as being variable in its ability to produce coagulase and differentiated between it and *M. pyogenes* var. *albus* on the basis of pigment production. The pathogenic staphylococci have also been described frequently as "hemolytic staphylococci" and the nonpathogenic strains as "nonhemolytic"; hemolysis is a variable characteristic depending on the culture medium and blood employed. Therefore, it is not always possible to state with certainty which species of staphylococci have been discussed in the literature unless the authors specified the methods employed for species differentiation. For the same reasons, it is difficult to assess the role of *Staphylococcus albus* in infections. Strains reported isolated from fatal infections and

Table 98. Phage Types of Coagulase-Positive Staphylococci Recovered From All Cultures of Postoperative Wound Drainage, All Wounds, Combined Hospitals

Total number of isolates: 149 - typable) 334 coagulase-positive Staph. of 1,931 cultures
185 - nontypable)

Phage type	Number of isolates	Phage type	Number of isolates
29	1	47,53,75,77	1
29,52	2	47,54	4
29,52,80	4	47,54*	1
29,79,80	1	47,53,54,75,77	3
29,52,52A,79,80	2	53	7
29,52,52A,79,80,81	1	53,77	7
52	8	53,77*	1
52,80	4	53,54	1
52,81	4	53,54,77	2
52,52A,80	3	53,54,75,77	1
52A,79	5	53,83	1
52A,80	2	54	2
79	2	54,77	3
79,80	2	54,73,75,77	1
80	10	75	1
80,81	26	75,77	2
81	4	77	2
3A	2	77*	1
3A,3B,3C	2	29,79,80,7,77	1
3B,3C,55,71	1	52,7,42E,54	2
3C	1	52A,79,6,53,77,83	1
6	1	52,52A,79,80,42D,44A	1
6,42E,53,75	1	3A,71,187	1
6,47,53,54	1	3B,3C,6,42E,47,42D,81	1
6,7,47,54	1	53,77,81	2
7	4	53,77,83	2
7,77	1	6,47,53,54,77,83	1
7,47	1	7,77,83	1
7,47,53,77	1	6,42E,81	1
7,54,75	1	54,42D	2
47	1	83	4
		187	2

*Cultures containing two or more specific coagulase-positive staphylococcus types counted only once.

classified as S. *albus* on the basis of pigmentation may actually have been coagulase-producing strains, and would therefore be considered as S. *aureus* today.

Escherichia sp. were isolated from 22.3 per cent of the postoperative drainage cultures of wounds that developed infection, followed by *Proteus sp.* and *Pseudomonas sp.*, each with a frequency of recovery of approximately 13 per cent (Table 86). Interestingly enough, 16.0 per cent of the clean wounds developing infection and 8.3 per cent of those not developing infection yielded *Escherichia sp.* (Table 87, 88). For the five hospitals participating in the study, the frequency of recovery of *Escherichia sp.* from postoperatively infected wounds of all classifications ranged from 19.2 to 28.9 per cent (Table D-3), and from clean wounds, from 11.3 to 26.7 per cent (Table D-10).

The occurrence of gram-negative bacteria associated with postoperative infections has been of growing concern (Altemeier, 1958). Eliason and McLaughlin (1934) reported the *bacillus coli* to be the organism most frequently isolated from postoperative infections after herniorrhaphy and appendectomy. Clarke (1957b) reported the *coliform bacillus* released from deep abdominal abscesses to be the most common cause of breakdown in clean, dry wounds. Dineen (1961) reported *E. coli* recovered from 20 per cent and *Proteus vulgaris* and *Pseudomonas pyocyaneus* each from 8 per cent of postoperatively infected wounds. The frequencies with which these organisms were recovered from clinically uninfected wounds (Table 86) and in each category of wound (Table 88) provoke speculation as to the sources of these and other species of bacteria usually associated with the intestinal flora.